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For: **METHOD AND APPARATUS TO  
CONTROL LOADED ISOTOPIC FUEL  
WITHIN A MATERIAL**

previously "Systems To Control Nuclear Fusion  
of Isotopic Fuel Within A Material"

This is a Continuation of Serial no. 07/ 760,970

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**METHOD AND APPARATUS TO CONTROL LOADED  
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The present invention to control loaded isotopic fuel within a material uses a two-stage method which involves a first stage of electrode loading, and then, a second stage of sudden rapid ("catastrophic") flow of hydrogen within the metal. The apparatus includes a novel cathode, novel anode, and heat pipes, to improve reaction rates. The apparatus includes means to extract products. The apparatus includes intraelectrode barriers to obstruct the movement of the isotopic fuel. The apparatus includes thermal and electrical busses, and enables integration of smaller units into larger assemblies.

The present invention relates to processes and systems involving loading, such as palladium internally filling ["loading"] with deuterons or deuterium (an isotope of hydrogen), but it has relevance as well, to storage devices, to energy systems, and to metallurgy.

By way of background and to place reasonable limits on the size of this disclosure, the following publications are noted:

#### U.S. PATENT DOCUMENTS

Serial number    Filing Date

07/339,976    04/18/1989    Swartz, M.

07/371,937    06/27/1989    Swartz, M.

#### FOREIGN PATENT DOCUMENTS

#### OTHER PUBLICATIONS

The present invention relates to electrochemical reactions in or about metals, such as palladium which has been electrochemically loaded with deuterium, but it has relevance as well, to hydrogen storage, fuel cells, nuclear fusion, and other reactions in pressure-loaded metals such as titanium or palladium filled with deuterium, and to the broader field of metallurgy and engineering in or about metals, including Groups IVb, Vb, and some rare earths.

The following journal articles and papers and may be used by way of background material and to supplement this specification:

C. A. HAMPEL, Rare Metals Handbook, Reinhold Publishing Corp, (1954).

M. HANSEN, Constitution of Binary Alloys, McGraw-Hill Book Co., Inc. (1958).

C. J. SMITHELLS, Metals Reference Book, Butterworths Scientific, (1949).

H. H. UHLIG, Corrosion and Corrosion Control, John Wiley & Sons, Inc., (1971).

M. R. SWARTZ, "The Catastrophic Active Medium Theory of Cold Fusion", submitted to Fusion Technology, September 1991 [pub. tk ]

Controlled reactions in loaded metals offers the possibility of more efficient and inexpensive energy.

However, there are problems. First, the desired reactions are not well controlled. The proven difficulties of loading, the slow initiation of the desired reactions, and the difficulty in controlling the reactions has limited research and development of this technology.

Second, prior to the desired reactions, the cathodes must be filled with deuterons to concentrations which require significant times of charging.

Third, palladium, the preferred metal of these reactions, is expensive.

Fourth, the rates of the desired reactions are very low in the steady state.

Accordingly, it is a principal object of the present invention to provide a novel method and system to control and enhance desired loading reactions.



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The foregoing objects are achieved in a system which includes in combination:

- a novel two-stage loading device, containing in combination:
  - a cathode able to be charged from a novel anode with deuterons at a high efficiency,
  - a deuteron impermeable barrier to increase the rate of desired reactions,
  - a thermal pipe to remove heat,
  - a modified solution consisting of a gel containing lithium deuterioxide and palladium deuterioxide,
  - a structural barrier to minimize catastrophic loss of said cathode,
  - a composite character of said cathode to minimize catastrophic loss of said cathode,
  - a structural barrier external to said cathode to minimize catastrophic loss of said cathode, and
  - an external casing to provide uniformity and plug-in-ability of said device into,
  - a superassembly which allows integration of the smaller energy producing devices.

The invention is hereafter described with reference to the accompanying drawings in which:

FIGURE 1 symbolically shows the compartments used to analyze an electrochemical reactor. The cathode is dissected into four regions, and three compartments within the metal itself. The flow of deuterons is shown by arrows.

FIGURE 2 is a simplified two-dimensional diagram which schematically shows the cathodic compartments used to describe an electrochemical reactor. Although the cathode is divided into four regions, only three are shown in this figure, for simplicity.

FIGURE 3 shows the change in hydrogen binding for palladium, along with Taylor series expansion at two temperatures.

FIGURE 4 shows the output of a simulation of a qualitative model used to test the catastrophic active medium (CAM) theory.

FIGURE 5 shows a typical experimental setup with a cruciform sacrificial cathode of palladium.

FIGURE 6 a simplified two-dimensional diagram which schematically shows the effect of providing intracathodic materials to quench mechanical crack propagation and subsequent breakdown of said cathode.

FIGURE 7 shows a device with axial electrochemical loading of a cylindrical cathode, surrounded by a heat pipe, and a expansion barrier.

FIGURE 8 shows a vertical cross-sectional slice of a device, showing structural external casing support system, a centrally placed axially-filled cathode, a coaxial deuteron-barrier and coaxial expansion-barrier.

FIGURE 9 is a cluster of seven devices, held together by an external structural casing support system, and an intercluster thermomechanical material filling the spaces between said devices.

FIGURE 10 shows a vertical cross-sectional slice of a device, with a central axially-filled cathode, two coaxial deuteron-barriers and an inner thermal pipe.

FIGURE 11 shows a vertical cross-sectional slice of a device with a coaxially-filled cathode. The electric fields are in the radial direction. Also shown are an inner coaxial deuteron-barrier and thermal pipe.

FIGURE 12 shows three devices mounted to the CAM device integration board. Said board is not yet inserted into a device receptor apparatus which contains electrical and thermal connectors held in a mechanical connecting system.

FIGURE 13 is a crossectional drawing of a lamellar CAM reactor. This device has two orthogonal applied electric fields. The second applied electric field intensity is delivered after full charging. Between these slabs of the cathode alternate deuteron-impermeable barriers.

FIGURE 14 shows three lamellar CAM reactors. Each device is equipped with orthogonal applied electric fields. Said apparatus has a thermal bus connected to the heat pipes which are held within a mechanical connecting system.

FIGURE 15 is a crossectional drawing of a device used to ignite a CAM reactor. External structures are near circumferential in location, and are used to squeeze the CAM reactor.

FIGURE 16 is a crossectional- drawing which shows three pressure-ignited CAM reactors. Each reactor contain, heat pipes, and thermomechanical connector for assembling the heat pipes to the external thermal bus.

FIGURE 17 is an isometric view of a thick film device located in a transistor-like header, with six leads.

FIGURE 18 is a crossectional drawing of a device to extract and isotopic product from a reactor. A magnetic field is applied.



Turning now to the figures:

Figure 1 symbolically shows the compartments used to analyze an electrochemical reactor. Figure 1 gives organization to the different parts of a simple reactor referred to in this disclosure. It is not meant to be physically realistic with respect to size. The cathode is dissected into four regions. Three compartments are shown within the metal itself. The flow of deuterons is shown by arrows. The label 1 represents the metallic cathode, usually palladium in the preferred configuration. The labels 2 and 3 represents compartments 2, and 3 respectively, which are discussed in detail below. The label 7 represents the anode which in the preferred embodiment is composed of palladium. The label 6 represents the solution consisting in the preferred embodiment of a gel containing antidesiccant, in combination with LiOD, palladium salts, and heavy water ( $D_2O$ ). The power supply and control unit consists of a current source and FUSOR reactor control device as described in Swartz (1989), and are not shown in the figure. For simplicity, the electrical connections, heat removing apparatus, and several improvements described in this disclosure are not shown in figure 1.

The application of said power source creates an applied electric field intensity which produces cation flow towards the cathode. There results in the near cathode solution (labeled as 5 in figure 1) a buildup of deuterons, and a low dielectric constant (gas bubble) layer. The bubbles are labeled as number 10 in figure 1. There may be spikes or on the cathode (labeled as 11 in figure 1).

Classically, an electrode in a deuteron solution at equilibrium should measure potentials associated with the Nernst equation. However, during the reaction, the system is not at equilibrium. Thermodynamics assumes equilibrium but tells nothing of the rate. Therefore, a quasi-1-dimensional model can be used to describe the situation external to the cathode. In the absence of solution convection, molecular flux ( $F$ ) results from both concentration gradients and electrophoretic drift.

$$F(D^+) = -\left[ B \cdot \frac{d[D^+]}{dz} \right] - \left[ \mu \cdot [D^+] \cdot \vec{\nabla} \Phi \right]$$

Coupled equations thus determine the distribution of deuteron species in the bulk solution.  $K_f$  is the bulk rate of the desired reactions.  $K_c$  is the rate at which deuterons physically enter the palladium cathode.  $B$  is the diffusivity.

fusion?  
constant?  
value?

flow into metal

of what?

$$\frac{d[D^+]}{dt} = -K_f + \left[ B \cdot \frac{d^2[D^+]}{dz^2} \right] + \left[ \mu \cdot [D^+] \cdot \frac{d^2[\Phi]}{dz^2} \right]$$

constant?

$$+ \left[ \mu \cdot \frac{d[\Phi]}{dz} \cdot \frac{d[D^+]}{dz} \right] - K_c$$

what are these

For simplicity, a number of approximations are made, such as no free charge density. In addition, deuteron penetration occurs at the cathode, and is electron limited, at an efficiency of  $E_c$ , so that the following steady state expression for the initial coefficient of the final spatial distribution of deuterons is:

$$D^+(z) = \frac{\left( \frac{E_c}{A \cdot F} \right) \cdot \sqrt{\frac{K_f}{B}}}{\cosh \left( \sqrt{\frac{K_f}{B}} \cdot L \right) - 1}$$

What is A, what is F, what is  $K_f$ ?  
What is L? What is  $E_c$ ?



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This occurs until, by a second catastrophic process, the fusion-defect-site is no longer confined. The final reactions in the CAM theory ends with the opening up of the defect or fissure through a large crack (compartment 3). By this theory the fissures are the result of the catastrophic desaturation of the active medium that was previously fully deuterated (e.g. in the preferred embodiment palladium or titanium).

The CAM theory may offer explanations for the tremendous "difficulties" observed by many experimenters attempting to repeat experiments, for the bursts of excess energy seen, for the very tardive appearances of both the excess energy and those bursts. The CAM theory begins at the cathode, labeled 1, by taking into account the special character of palladium and titanium with respect to deuterons and hydrogen.

In most metals (e.g. aluminum, cobalt, copper, iron, nickel, platinum, silver, and tin) the deuterium solubility is described by the experimental relation [where  $K$  is the Sievert constant, and  $p$  is the partial pressure of deuterium gas ( $S = K * \sqrt{p}$ )]. However, all such metals have low solubility, and only dilute solutions are stable (about one deuterons per 10,000 or more metal atoms). Furthermore, in such metals deuterium solubility is endothermic. Therefore, the solubility for these metals increases with temperature.

In contrast within palladium and titanium (and other Group IVb and Vb metals and some rare earths such as cerium, lanthanum, niobium, tantalum, thorium, vanadium, zirconium) much different behavior occurs. First, much more concentrated solutions can exist. For these metals the greater deuterium concentrations mean that they act like emphores ('vases', similar to the biomaterial myoglobin). Furthermore, the deuterium binding in these metals is exothermic. This indicates that the deuterons reside in shallow energy traps located within and throughout the lattice. Most importantly for the CAM theory, the deuterium binding capacities decrease with temperature for these metals.

The deuteron-laden metal lattices change significantly with increasing deuteron loading. An extensive literature, involving solubility isotherms and x-ray results demonstrates two solid solutions of protons in palladium. During the time of deuteron loading there is progressive increase in the volume of the cathode. A 5000 atmosphere internal pressure is consistent with the 4% plastic deformation following deuterium loading.

Classically, the atomic ratio of deuterons to palladium is used to describe the quantity of deuterons in metal.

$$(\text{Pd D}_x), \text{ where } x = \frac{[\text{numberD}]}{[\text{numberPd}]}$$

This is broken up in the CAM model. The total deuteron content in a given volume of palladium cathode is modeled as the sum of the deuterons physically located in compartments 2 and 3 (and in any amorphous palladium hereinafter ignored for simplification) and those deuterons which are entrapped within the palladium lattice (compartment 1). The quantity of the former amount is modeled as the product of the Henry gas solubility coefficient and the deuterium partial pressure  $[P_{D_2}]$

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$$P_{D_2} = [\alpha \bullet (P_{D_2}) \bullet f] + [(1 - f) \bullet y_D \bullet \hat{n}]$$

$f$  is the fractional amount of defect sites (e.g. compartments 2 and 3) in the beta-phase palladium. For a solid metal cathode, the quantity of dissolved deuterons in compartments 2 and 3 (first term above) is small compared to that bound to palladium because most of the metal resides in a crystalline lattice. Thus,  $f$  is therefore close to zero.

This relation can be examined in the limit of  $f$  approaching zero by l'Hospital's Rule. That analysis indicates that the deuteron pressure is related to the quantity of bound deuterons as: .

$$\lim [D_{2(f \rightarrow 0)}] = \frac{\hat{n} \bullet y_D}{\alpha}$$

This indicates that CAM model in that limit is consistent with well-known solubility laws of deuterons in most materials.

Figure 3 shows the hydrogen-solubility (hereinafter called saturation or binding) for palladium as a function of temperature, along with Taylor series expansions at two temperatures. The curve shows the quantity in cubic centimeters (STP) contained in 100 grams of palladium. The total quantity of hydrogen in palladium is markedly temperature dependent. The Taylor series expansion shows that the differential desaturation with temperature increases with decreasing temperature. The sharp decrease in total quantity bound for an increase in temperature may drive the desired reactions by catastrophically displacing deuterons into compartment 2.

Many of the technologies now described are useful no matter how filling of the deuterated metal occurs.

Some preliminary comments are in order. Because the process and apparatus are independent of method of filling said metal, a greater examination is now given to said deuterated metal. The actual loading of the palladium will be ignored for the CAM model and theory, but said deuteron loading does play a significant part of the device described below.

The CAM theory considers palladium as an "active" medium because unlike most other metals, palladium has a deuteron capacity which falls rapidly as the temperature rises. The temperature effect upon deuteron desaturation, in palladium, usually begins in the beta phase. The binding decreases so markedly with temperature that there is almost a decade decrease from just 0 to 50 Centigrade. At 110 C, the beta phase converts to the alpha phase with an additional 0.3 moles of  $O_2$  gas released.



In the CAM model there is assumed to be rapid mass transfer from compartment 1 to 2 as the catastrophic desaturation occurs. This is a reasonable assumption because of the deuteron diffusivity in palladium increases with temperature. It is that increase in diffusivity which enables palladium foils to remove hydrogen and deuterium from other gases at elevated temperature. The CAM hypothesis was tested in a computer simulation wherein the desired reactions were hypothesized to occur only in the metal-surrounded free gas compartment located physically within the cathode (figure 1). The fractional saturation was approximated by expressions for both pressure and temperature qualitatively similar to those reported.

$$y_D = 1 - \exp \left[ \frac{-P_{D_2}}{c_1 \cdot T} \right]$$

The last qualitative assumption used was that the temperature would increase very slightly with the desired events, secondary to markedly increased pressures for deuteron pressures greater than 50 atmospheres.

The qualitative model used to test the catastrophic active medium (CAM) theory did show that in the model the metal was capable of exothermic catastrophic fractional desaturation. Figure 6 shows the results of that simulation. The same phenomenon occurred for several different such qualitative formulations. The three curves are A) the normalized deuteron pressure (in atmospheres), B) the normalized system temperature, C) the fractional saturation ( $y_D$ ) of the active medium (palladium).

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Figure 4 shows that as current is delivered to the cathode there is a steady increase in deuterium within the cathode. Initially, because of the large capacity for deuteron binding in compartment 1, the deuteron pressure rises only slightly. Thus the sublinear relation of total deuteron content to pressure, shown by the CAM model may also be consistent with the  $\sqrt{p}$  law, experimentally derived, and discussed above. Figure 4 shows that the computer model predicted that compartment 2 is suddenly, catastrophically, fed deuterons from the larger crystalline palladium lattice compartment. It can be seen that there occurs a critical catastrophic event wherein the fractional saturation suddenly falls as the temperature rises in concert. As the active medium (palladium) catastrophically releases deuterons to the defect sites astronomic pressures develop. In a crescendo fashion, the desired reactions result and the cathodic temperature rises even further. The temperature in compartment 2 rises further, but is limited as phonons carry off the excess energy of the reactions. The active medium around the defect site, in which the desired reactions occur, reabsorbs phonons resulting in the observed excess heat.

The catastrophe occurs precisely because the further temperature increase causes even more flux of deuterons into compartment 2, further increasing the likelihood of the desired reactions. The reaction is driven by the catastrophic fractional desaturation of deuterons from the crystalline palladium lattice, previously filled to capacity. The catastrophic mass transfer of deuterons to the defects (from the saturated metal, not the solution) enables the desired reactions to occur. Also the electrical charging of the cathode to a high negative voltage should enhance the reaction.

The reactions of deuterium continue until the crystalline palladium (the active medium because of its high fractional saturation and its exothermic desaturation tendency) is spent of its

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deuterons or until, by a second catastrophic process, the fusion-defect-site is no longer confined. At that point, catastrophic exposure of compartment 2 to the ambient occurs creating compartment 3. The intracathodic compartment 3 of the CAM theory is known from endstage deuteron (or hydrogen) embrittlement. This compartment usually declares itself when the dissolved deuterons, after entering a metal through a corrosion reaction or by cathodic polarization, explode into the ambient as the metal fissures or otherwise irrefutably changes shape. The fugacities involved are enormous ranging from 5000 up to an estimated  $10^7$  atmospheres for hydrogenated palladium.

↑ ?? how do you maintain reaction & integrity

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One special compartment 2 should be noted. Because the solubility of deuterium in water is relatively low, the electrolyte solution itself acts as a barrier to create another type of compartment 2 which is more compliant because of the water (hydrogen bonds vs. covalent bonds of the palladium). The space charge formation, the low dielectric layers (gases) in front of the cathode, any spikes on the cathode, work together at this compartment 2 to create very large electric field intensities. Further ionization reactions contribute to activate the reaction.

Turning now to Figure 5 shows a typical experimental setup, but with a novel cruciform-shaped sacrificial anode of palladium in a solution (labeled 7). The preferred solution (6) contains palladium salts, lithium deuterioxide, and heavy water. The cruciform shape is the preferred shape of the anode in that as it is sacrificed to the solution (enabling efficient codeposition of palladium and deuterons) the surface area most nearly remains constant during its decomposition of said sacrificial anode. The connections to the electrodes are labeled as 81 and 82. The reaction vessel is labeled 8. The cathode is labeled as number 1.

This type of system, coupled with the FUSOR (JET Technology, Weston, MA) drive system, is capable of filling the cathode with deuterium from the solution. However, the deuterated metals could also be filled by codeposition of deuterium and palladium, or by high pressure deuterium gas.

In the following devices, heat pipes are included as well as a superassembly capable of removing excess heat.

In the following devices, palladium is the described preferred embodiment for the cathodes, but members of the group consisting of vanadium tantalum, niobium, lanthanum and cerium may also be used.

Furthermore, one improvement is that the cathode should be improved for deuteron solubility, while being stabilized from catastrophic deformation which would end the desired reactions. There are a number of methods by which this is accomplished.

Within the metal (labeled 1), there are several methods used in this device to minimizing catastrophic fracture. First, is the preferred use of cathodic binary alloys. Some palladium alloys (e.g. boron, silver or gold) exhibit, for intermediate compositions, peak levels of hydrogen (and deuteron) solubility.

Second, in the preferred embodiment manganese could be added to the palladium to decrease the susceptibility to deuteron cracking. Third, in the preferred embodiment said cathode is stabilized by an external barrier construction. Fourth in the preferred embodiment additional diffusion barriers are placed to obstruct the released deuterons.

In the preferred embodiment internal materials are added to decrease the likelihood of electrode deformation. For example a composite material could be fashioned using palladium and epoxy so that the electrode is more like bubblegum than like crystalline metal. Although the inter- and intramolecular forces are less, the bond energies increase because the important parameter is the product of force times distance. The weaker interactions, acting over longer distances, would lead to increased energies required to rupture the electrode.



Figure 7 is an isometric drawing of a CAM electrochemical device, and shows the direction of the electric field. Figure 7 shows a see-through view over the cathodic volume. This cutaway exposes the four concentric components of the device at that location. In this simplified CAM device, surrounding the cathode, in coaxial fashion, are a deuteron diffusion barrier (labeled 50) and an expansion barrier (labeled 40). These barriers are discussed in detail below. In this particular device, the cathode is axially-fed the deuterons. For simplicity, the power supply, control apparatus (including phonon drive, magnetic fields, thermal capture system and electrical connections) are not shown in figure 7. The electric field points from anode (labeled as 7) to the cathode (labeled as 1). In the device shown in figure 3, label 20 represents the structural casing wall which makes this CAM device “dry”. The enclosed solution, in the preferred embodiment actually consisting of a heavy water-LiOD-gel, and is labeled number 6. The device is shaped like a fuse and can be easily placed into, or removed from, an assembly and system used to both power the reaction and extract the excess heat. For simplicity, the power source, connections, and thermal extraction system are not shown.

Figure 8 shows a vertical cross-sectional slice of a CAM device, having an external structural casing support system, a centrally placed axially-filled cathode, a coaxial deuteron-barrier and coaxial expansion-barrier. The structural support system (labeled 20) encloses an axially-filled cathode for loading reactions consisting of a coaxial deuteron-barrier and coaxial expansion-barrier. The expansion barrier (labeled 40) surrounds the cathode and prevents expansion. Between the two is a deuteron impermeable barrier (labeled 50) which prevents outward diffusion of deuterons when the cathode is catastrophically desaturated of its deuterons. The barrier prevents loss of deuterons to the expansion barrier, and acts as a

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**BOOK REVIEW**

The cathodes are fashioned as cylindrical palladium surrounded by a deuteron impermeable (or relatively impermeable) barrier (e.g. tungsten or gold). The result would be that after a slow charge with deuterons, the catastrophic desaturation yields a rapid symmetric flux through the walls of the cathode cylinders - directly into the impermeable wall thereby increasing fusion. For simplicity, the power supply, FUSOR control apparatus including phonon drive, magnetic fields, thermal capture system and electrical connections are not shown in figure 9.

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Said apparatus has a thermal bus (labeled 107) connected to the heat pipes (labeled 70) which are held in a mechanical connecting system (labeled 20). The entire apparatus has a heat dissipative system which is not shown.

The purpose of the receptor apparatus is first to integrate the three (or more) CAM units. The three cathodic connectors are connected to the control apparatus. However, after loading the cathodes, the cathodic buses (106 and 107) are separated and a second electric potential is supplied between these two buses. The result is the second applied electric field which is shown in figure 13, but not in figure 14. The result is the piling up of deuterium at the deuteron-impermeable barriers (labeled 55 in figure 14). The energy is directed out via the heat pipes (70) and the thermal bus (107). The damage or rundown of one CAM unit is thus easily exchanged by replacement with a functional one.

Figure 15 is a crossectional drawing of a device used to activate a CAM reactor. The cathode is labeled 1. The solution or gel is labeled as 6. The mechanical casing is labeled 20. The deuteron impermeable barrier is labeled 55. In the figure the anode and the solution are not shown, because the cathode is axially loaded. The CAM device shown in figure 15 does not show, for simplicity, the thermal transfer equipment. External structures labeled 110 and 120 are near circumferential in location to the casing (20), and are used to squeeze the CAM reactor. The resultant pressure causes catastrophic desaturation. Also not shown in the figure are temperature control systems which can also activate the reaction.

w?





coenergy with respect to distance in the axial direction, and is proportional to the square of the current, the square of the number of turns in the coil (300), and said differential magnetic susceptibility. *how*  
The products are removed at the product barrier (labeled 350). If said isotopic product is of lower magnetic susceptibility, then the coil is moved toward the portion of the cathode near to the solution (6).

A two-stage method which involves a first stage of loading, and then, a second stage of sudden rapid ("catastrophic") flow of hydrogen within the metal.

An apparatus including a novel cathode, novel anode, and heat pipes, to improve reaction rates. An apparatus including means to extract products. An apparatus including intraelectrode barriers to obstruct the movement isotopic fuel.

Modification of the invention herein disclosed will occur to persons skilled in the art and all such modifications are deemed to be within the scope of the invention as defined by the appended claims.